

Evaluation of selected heavy metals on the artisanal gold mining sites in North Rift Region, Kenya

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Abstract

ASGM activity significantly contributes to the economies of developing countries with a consequent impact on the socio-ecological systems. The impacts are largely due to the wide use of mercury in the extraction processes. It also deforestates the exploited areas with consequent loss of biodiversity and ecosystem functions. ASGM has varied impacts of adverse health effects and it is said that mercury has more significant health effects than other heavy metals (Cd, Pb, As, and Cr). Due to dearth in the studies on artisanal mining in Kenya, the study sought to evaluate the concentration levels of selected heavy metals on the artisanal mining sites in Nandi and West Pokot Counties of Kenya in order to determine their nature, concentration levels and suggest mitigation measure. The study was done in two artisanal gold mining sites in Kapsaos in Nandi County and Sekker in West Pokot County in Kenya and employed a comparative analysis to examine the attributes of these locational spaces. Thirteen samples were randomly collected from tailings at different points from the tailing disposal site in Kapsaos areas and Sekker site. The samples were transported prepared and stored at Environmental Chemistry Laboratory, the University of Eldoret where it was subjected to Atomic Absorption Spectroscopy (AAS). The laboratory analysis results showed that the samples from both artisanal gold mining sites contained several heavy metals which included Chromium, Cadmium, and Lead. Overall, the mining sites in Nandi County had the following concentration of Cr, 0.4195 ppm, Cd, 0.2470 ppm, and Pb, 0.6300 ppm, while the mining sites in West Pokot county had the following concentrations: Cr, 0.1790 ppm; Cd, 0.0050 ppm; and Pb, 0.7400 ppm. Besides, the concentrations levels of Lead and Cadmium were above the WHO guidelines. A casual look at the concentration levels indicates that the mining sites in Nandi County have higher concentration levels of selected heavy metals (Pb, Cd and Cr) than in West Pokot County which was attributable to the ASGM activities. The study concluded that ASGM activities excavates, destabilizes the stable states of elements and then concentrates them. Finally, the study recommends that ASGM be upscaled instead of being frowned upon. Further studies on the potential socio-economic impacts on the ASGM activities in Western Kenya because the activity is considered a complementary/supplementary economic activity.

Keywords: Artisanal and small scale gold mining (ASGM), artisanal mining, selected heavy metals, mercury, heavy metal pollution

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1. Introduction

As early as 2004, several studies reported ASGM activities generated between 10% to 15% of global gold output (Razanamahandry *et al.*, 2018; Veiga, Angeloci-Santos & Meech, 2014), however, estimates by Basu *et al.*, (2015) ranged between 20%–30%. This indicates the increasing significance of the ASGM activities to multitudes who participate in the activity. The activities are primarily found in three regions of Asia, Africa and South America (Esdaile & Chalker, 2018) where is positively seen by millions of persons as both a subsistence and a livelihood. But on the contrary, it is also the leading source of mercury pollution globally (Sippl, 2015). It is seen an economic mainstay activity providing direct employment to over two million people in rural sub-Saharan Africa (Hilson, 2009) with up to 80% of small-scale miners worldwide operating without formal authorization (Tschakert & Singha, 2007).

In many developing countries, ASGM activity significantly contributes to the economies of those countries. Shandro, Veiga & Chouinard (2009) observed that ASGM is responsible for over 90% of gold production in Mozambique and is a significant economic activity in Burkina Faso (Black *et al.*, 2017). It makes up approximately 90% of the total mineral production in Democratic Republic of Congo (Bashwira *et al.*, 2014) while accounting for a good percentage in the economy in Senegal (Persaud *et al.*, 2017). In Tanzania, the sector contributes about 2.3% of the GDP (Kitula, 2006). In ASGM activities, gold is extracted mainly from alluvial deposits along rivers,

waterways and terrestrial soils (Donkor *et al.*, 2006) and varies widely in terms of its scope and practice (Schmidt, 2012).

ASGM is low tech, labour-intensive mineral processing and excavation activity (Hilson, 2009) and commonly uses mercury in its extraction process because of its availability, efficiency and historical usage, thus it can be inferred that with the global expansion of ASGM activities, there is a likely commensurate increase in the mercury usage (Basu *et al.*, 2015). The artisanal mining processes mainly involves the excavation process where the natural vegetation is removed with the extensive excavation. Then, trial and error process of observation to identify the gold vein is used and once, observed, the rock bearing deposited is excavated either manually or mechanically for further processing (Esdaile & Chalker, 2018; Donkor *et al.*, 2006). Large boulders are mechanically pulverized and then soaked water to form a concentrated where the heavier gold-containing ores are caught and concentrated while the remaining concentrate is re-assembled in pans (Tschakert & Singha, 2007).

The undesirable sediments are separated with final concentrate being mixed with mercury which is mixed with hand until a lump of mercury-gold amalgam is formed (Tschakert & Singha, 2007). The amalgamation process may be repeated 3 or 4 times to maximize gold extraction (Esdaile & Chalker, 2018). Excess mercury is then recovered and stored for re-use while the amalgam is then roasted in the in an open fire or a blowtorch to form a gold nugget (Esdaile & Chalker, 2018). The amalgam is typically between 40% and 80% mercury and heated—often with a torch or over a stove to evaporate the mercury and isolate the gold which while typically contain up to 5% residual mercury (Esdaile & Chalker, 2018). This is the end-product that is readily sold (Tschakert & Singha, 2007).

The ASGM activities pose a serious environmental threat to the human and the environmental activities due to its indiscriminate use of mercury (Donkor *et al.*, 2006; Tschakert & Singha, 2007). The resulting environmental pollution remains a threat to the socio-ecological balance (Donkor *et al.*, 2006) and may trigger significant environmental and social problems because of the large deposits of wastes and/or tailings, which when exposed to air are oxidation and weathered by precipitation, and subsequently pollute water resources (Schwarzenbach *et al.*, 2010). Cordy *et al.*, (2011) estimated that only 50% of the mercury used in recovered while 50% is lost in two stages; the amalgamation and burning processes (Tschakert & Singha, 2007) where 46% is lost in tailings while 4% is lost in the burning process. Due to these estimates, ASGM activities are considered as the largest source of mercury pollution (Esdaile & Chalker, 2018; Clifford, 2017). The usage of Mercury in Nandi County is illustrated by the image in Figure 1 below.



Figure1 Mercury use in mining in Nandi County

1.1 Heavy metal pollution

Artisanal small-scale gold mining, both at present and in the past, has had a major impact on soils and ecosystems (Grimaldi, Guédron & Grimaldi, 2015; Shandro, Veiga & Chouinard, 2009). The impact is largely due to the wide use of mercury in amalgamation a process (Veiga, Angeloci-Santos & Meech, 2014; Miserendino *et al.*, 2013) where the unrecovered mercury is either released directly into the environment or processed further depending on the level of sophistication (Esdaile & Chalker, 2018). The real annual estimates of the amount of mercury being released into the environment by the ASGM activities ranges between 650 metric tonnes to 1600 metric tonnes (Esdaile & Chalker, 2018; Telmer & Veiga, 2009).

This release is broken down into gaseous discharge or vaporized mercury into the atmosphere where approximately 350 to 450 metric tonnes are released (Telmer & Veiga, 2009) and between 650 to 1000 metric tonnes of elemental and particulate mercury being released into the hydrosphere/environment (rivers, lakes, soils, tailings) (Veiga, Angeloci-Santos & Meech, 2014; Schmidt, 2012; Basu *et al.*, 2015). The magnitude of mercury use in ASGM activities is compounded by the fact that gold is precious and is fetching higher prices in the international markets and this tends to have a positive effect in the supply and usage of mercury (Esdaile & Chalker, 2018).

In addition to Mercury pollution, ASGM activities also contribute to the increase in the concentration of heavy metals, metalloids such as arsenic (As) and heavy metals such as lead (Pb), mercury (Hg) and cadmium (Cd) are naturally occurring pollutants but their environmental levels have increased in artisanal mining communities (Schwarzenbach *et al.*, 2010). Several studies have cited the presence of metalloids and metals in various ASGM communities in several regions of the world including Ghana (Basu *et al.*, 2015; Obiri *et al.*, (2016)), Zimbabwe (Mudyazhezha & Kanhukamwe, 2014), Nigeria (Nuhu, Sallau & Majiya, 2014), Ecuador (Miserendino *et al.*, 2013) among others.

According to Grimaldi *et al.*, (2015), ASGM is drastically changing land use with a considerable impact on the entire social-ecological system in several ways. First, the removal of top vegetation through the strip of the surface cover leading to the destruction of soil structure and affects the quality of water, second, the physical process of excavation and crushing damages the topography, third, the use of toxic metals and compounds in the amalgamation process without due care chemically pollutes air, surface and underground water and lastly, the indiscriminate disposal of tailings and waste affects the physical and chemical properties of natural resources.

ASGM also causes complete deforestation of the areas exploited and consequently a loss of biodiversity and ecosystem functions, landscape modifications and soil degradation (Grimaldi *et al.*, 2015). Soil and water reservoirs (ground and surface water) are contaminated by the accumulation of heavy metals and metalloids through the discharge of mine tailings (Wauna & Okieimen, 2011). For instance, in Southern Africa and Latin America, ASGM has led to contamination of water reservoirs affecting the health of the miners and community (Rojas, Drake *et al.*, 2001). Evidence indicates that ASGM communities in Ghana are exposed to multiple toxic elements including As, Pb, Cd, and Cr (Basu *et al.*, 2015).

1.2 Health Effects

Current studies into ASGM communities indicate that miners occasionally experience neurological effects, kidney effects, and possibly immunotoxic/ autoimmune effects from Hg exposure (Gibb & O'Leary, 2014) and other heavy metals. Several metals and metalloids such as Cd, As, Pb and Hg are toxic to humans and have multiple adverse health effects, even at low concentrations (Schwarzenbach *et al.*, 2010; Obiri *et al.*, 2016). The health assessment reported kidney dysfunction, neurological disorders and symptoms, and immunotoxicity/autoimmune dysfunction in individuals living in or near an ASGM activity (Gibb & O'Leary, 2014).

There are varied impacts of adverse health effects from the ASGM activities with Mercury having more significant health effects than other heavy metals such as cadmium, lead, aluminium, iron, and arsenic (Houston, 2011). Mercury is known to induce mitochondrial dysfunction (Houston, 2011) and has been associated with adverse cardiovascular outcomes such as coronary heart disease, myocardial infarctions, cerebrovascular accidents, cardiac arrhythmias, heart rate variability, atherosclerosis, and renal dysfunction (Basu *et al.*, 2015). Other clinical consequences of mercury toxicity include, hypertension, increased carotid intima-media thickness and carotid artery obstruction, generalized atherosclerosis, and renal dysfunction, insufficiency, and proteinuria (Houston, 2011).

Evidence indicates that even at low exposure levels, Mercury may have adverse effects on the neurologic and body system which tend to vary according to individual susceptibility and other confounding variables (Karagas *et al.*, 2012). The overall vascular effects of mercury include increased oxidative stress and inflammation, reduced oxidative defence, thrombosis, vascular smooth muscle dysfunction, endothelial dysfunction, dyslipidemia, and immune and mitochondrial dysfunction (Houston, 2011) with a variety of potential health effects ranging from foetal growth, a variety of health outcomes such as neurologic function, the cardiovascular system, and immune function in both adults and children (Gibb & O'Leary, 2014). In South America countries of Peru and Brazil, exposure to mercury has resulted in kidney dysfunction that leads to kidney failure (Rodriguez *et al.*, 2017).

The main problem of heavy metals pollution is their persistence in soil and their tendency to bioaccumulation, their uptake by a human through food chain causing health problems and the poisoning of soil microorganisms (Odousoro *et al.*, 2010). Therefore, exposure to ASGM activities had increased population morbidity leading to loss of productivity (Miserendino *et al.*, 2013). Increase in tailings and sediments from mining sites have led to heavy metals contamination of ground and surface water and soil (Muezzinoglu, 2003). There is a dearth in the empirical studies on the artisanal mining among communities in Kenya and therefore, the study sought to evaluate the concentration levels of selected heavy metals on the artisanal mining sites in Nandi and West Pokot Counties of Kenya in order to determine their nature, concentration levels and institute any mitigation measure that improves the environmental, social and health effects on the miners and community.

2. Materials and Methods

2.1 Study Area

The study was done in two artisanal gold mining sites in Nandi and West Pokot Counties in Kenya. Nandi county is in the western region of Kenya and occupies an area of 2,884.4 Km², and it is bordered by the equator on the southern part and extend to the north at the latitude of 0°34'N. The western bordering extends to longitude 34°45'E and the eastern boundary reach longitude 35°25'E. Artisanal gold mining in Nandi county takes place in Kapsaos and Chemase wards (RoK, 2001). West Pokot County is situated on the Western boundary with Uganda and borders Turkana County to the North and North East, Trans Nzoia County to the South, Elgeyo Marakwet County and Baringo County to the South East and east respectively. The County lies within Longitudes 34° 47' and 35° 49' East and Latitude 10 and 20 North occupies of approximately 9,169.4 square kilometres. The county has limited gold deposits along river Muruny, Seker and parts of Alale but alluvial mining takes place along river Murruny passing through sekker and Weiwei wards (ROK, 2002).

2.2 Study Design

The study employed a comparative design which applied the use of the geographic information systems (GIS). A geospatial analysis carves out geography into mutually exclusive spaces and then examines the attributes of these locational spaces (Depoy and Gitlin, 2011). The choice of the study design was based on the notion that this type of analysis was more relevant to making a comparison of attributes to specific locations. The GIS located the following estimate coordinate points for Nandi County: 0° 0' 49.95"N, 35° 3' 48.95"E; 0° 0' 49.95"N, 35° 5' 24.95"E; 0° 0' 0.35"N, 35° 3' 48.95"E; and 0° 0' 0.35"N, 35° 5' 24.95"E for the Kapsaos mining site and the following estimate coordinate 1° 31' 57.10"N, 35° 24' 42.84"E; 1° 31' 43.49"N, 35° 26' 40.20"E; 1° 31' 27.10"N, 35° 26' 28.84"E; and 1° 33' 43.49"N, 35° 24' 40.20"E for the River Murruny, West Pokot County.

Once the locations had been identified the researcher purposively chose two wards in both counties; Kapsaos in Nandi County and sekker in West Pokot for the crucial comparative analysis of the attributes of artisanal mining activities. Once, completed the researcher embarked on the collection of samples from the mining sites in the two locations. The nature of mining in the two counties differs with underground mining being prevalent in Nandi County whereas alluvial mining being confined to West Pokot county. This illustrated by the images below, the left image shows an entrance to the mining shaft in Nandi County while the image on the right shows people undertaking panning in West Pokot County.



Figure 2 shaft in a mining site in Nandi County



Figure 3 Alluvial mining in West Pokot County

2.3 Sample Collection

Thirteen samples were randomly collected from tailings at different points from the tailing disposal site in Kapsaos areas, Nandi County and Sekker site, West Pokot County. The collected samples were air-dried to a constant weight to avoid microbial degradation (Kakulu, 1993) and put in polyethene containers rinsed with dilute Nitric acid. The samples were deposited at the Environmental Chemistry Laboratory, University of Eldoret, Kenya for analysis using Atomic Absorption Spectroscopy (AAS).

2.4 Laboratory Analysis

From the collected samples, two (2) grams of each sample was weight and ground into a fine powder using an acid pre-washed mortar and pestle. Each powder of the sample was transferred into an acid-washed round bottom flask containing 20 cm³ concentrated acid. The mixture was evaporated on a hot plate; the solid residue was digested with concentrated with a 3:1 ratio mixture of concentrated HNO_3 and HClO_4 for a period of 30 minutes at room temperature. The digested mixture was heated to a steady temperature of 150°C for a period of 6 hours to allow HClO_4 to evaporate completely (Jacob *et al.*, 2009). The mixture was cooled to room temperature and filtered using number 541 Whatman filter paper into 50 cm³ volumetric flask and made into the standard mark using de-ionized water. The filtrate sample was stored in pre-cleaned polyethylene storage bottles ready for analysis. Heavy metals concentrations were determined using AAS (model: Varian spectra-200) at the Environmental Chemistry Laboratory, University of Eldoret, Kenya. The instruments settings and operating conditions were in accordance with the manufacturer's specifications. The instrument was calibrated with analytical grade standard metal solutions (1 mg/l) in triplicates.

3. Results and Discussion

After laboratory analysis, the results of the metal concentration are presented in Figure 1 below. The analysis of the samples precluded Mercury metal because of the challenges of determining the concentration of the Hg within the county at that point in time. This exclusion does not rule out a higher concentration of Mercury in the samples from the Nandi County mining as illustrated by the images showing the use of Mercury in the amalgamation process.

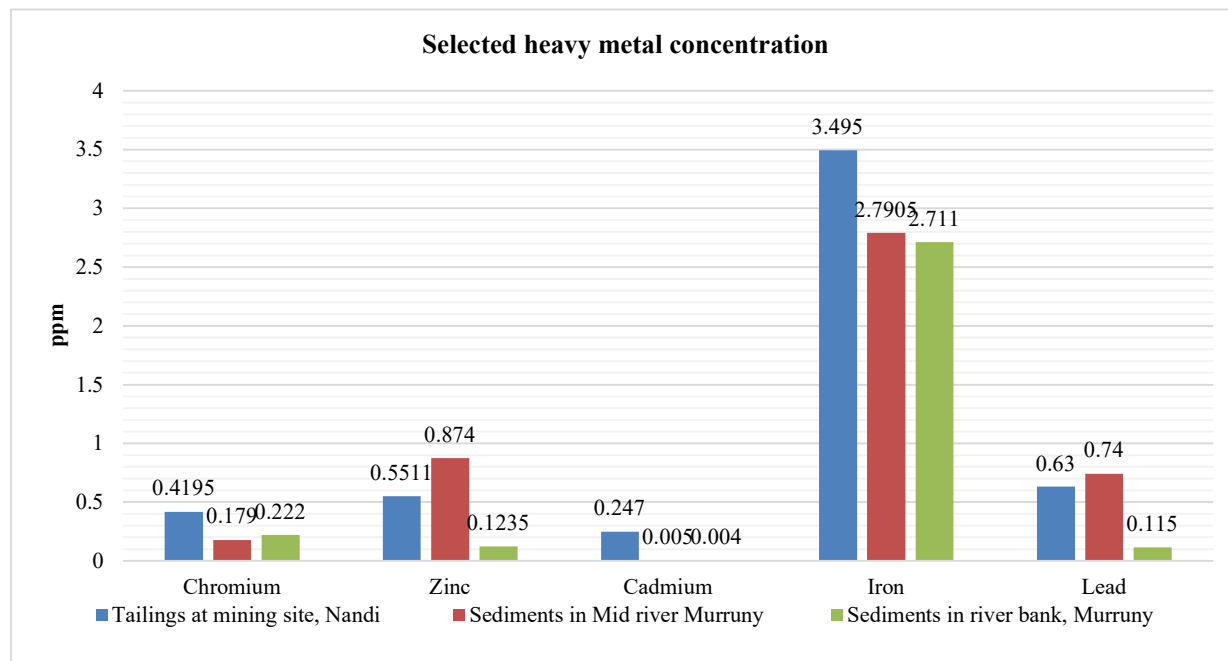


Figure 1: Mean Concentration levels of selected heavy metals

Based on the laboratory analysis results, the samples from mining sites in Nandi and West Pokot County contained several trace elements which included Chromium, Zinc, Cadmium, iron and Lead. Overall, the mining sites in Nandi County had the following concentration of Cr, 0.4195 ppm, Zn, 0.5511 ppm, Cd, 0.2470 ppm, Fe, 3.4950 ppm and Pb, 0.6300 ppm, while the mining sites in West Pokot county had the concentrations of the heavy metals: Cr, 0.1790 ppm; Zn 0.8470 ppm; Cd, 0.0050 ppm; Fe, 2.795 ppm; and Pb, 0.7400 ppm on the river bed and concentration of Cr, 0.2220 ppm; Zn 0.1235 ppm; Cd, 0.0040 ppm; Fe, 2.711 ppm; and Pb, 0.1150 ppm on the sediments.

In comparison, the average Iron concentration levels in Nandi mining area was 3.4195ppm while in West Pokot are was 2.7905 ppm at the midriver and 2.711 ppm on the river bank. The average Zinc concentration in Nandi mining area was 0.5511ppm, while in West Pokot, the mid-river was 0.1874ppm and riverbank was 0.1235ppm. The average Cadmium concentration in Nandi mining area was higher 0.247ppm while in West Pokot, the concentration at midriver was 0.005ppm and at the river bank was 0.004ppm. The average Lead concentration in Nandi was 0.63 ppm while in West Pokot the, mid-river had 0.74 ppm and 0.115 ppm on the river bank. Lastly, the average Chromium concentration in Nandi was 0.4195 while in West Pokot it was 0.179ppm at the river bank and 0.222ppm at mid-river.

Both Iron and Zinc are are essential nutrients required for various biochemical and physiological function(Tchounwou *et al.*, 2012) and the concentration of Zinc(0.874ppm & 0.551ppm) in samples from both Nandi and West Pokot counties was lower than WHO/FAO recommended guideline value of 5.0 ppm for Zinc, while the concentration of Cadmium in Nandi mining site(0.247ppm) was higher against WHO/FAO recommended guideline value of 0.01 ppm. The concentration of Lead in Nandi mining site(0.63ppm) and West Pokot site (0.74ppm) were higher than the WHO/FAO recommended guideline value of 0.30ppm. lastly, the concentration levels of Chromium in Nandi mining sites(0.4195ppm) and West Pokot sites(0.222ppm) were way below the against WHO/FAO recommended guideline value of 0.05 ppm. The WHO/FAO recommended guideline value for Mercury is of 0.030ppm

The concentration of the selected heavy metal (Lead and Cadmium) where higher than the WHO/FAO recommended levels however, their impacts on the miners could not be ascertained. Further, the use of Mercury in the amalgamation process could compound the health of the miners but the measurement of long – term impacts of these metals would require a longitudinal study. Several studies have profiled high concertation levels of As and Hg with other heavy metals elements Cd, Cr, Pb and Zn having varying concentrations (Van Straaten, 2000).

A casual look at the concentration shows that the mining sites in Nandi County have higher concentration levels of selected heavy metals (Pb, Cd and Cr) than in West Pokot County. This finding would be associated with anthropogenic activities of underground artisanal gold mining as opposed to naturally occurring rock weathering processes. First, all the concentration levels of the metals sampled including essential metals (Iron and Zinc) are higher when compared yet both counties have more or less similar altitudes and agro-ecological zone. Due to this, the rate of rock disintegration would be similar and thus there would be no difference in the concentration levels.

Second, the type of mining being undertaken in the sites would explain the levels of concentrations. Shaft mining is predominant in Nandi County significantly disturbs the concentration levels of heavy metals which are occurring in the natural states as opposed to alluvial mining which occurs in West Pokot county. The anthropogenic ASGM process of excavation, crushing and amalgamation process would disturb the elements and introduce them to the surface and concentrate them and in the process highlight the differences in concentration levels of these metals. This finding is supported by previous studies which indicated that occurrence of increased concentrations of heavy metals in the tailings is an indication of human-induced perturbations rather than natural enrichment through geological weathering (Davies, Tomlinson & Stephenson 1991; Binning & Baird, 2005; Eja *et al.*, 2008).

Thirdly, empirical studies on ASGM activities have indicated that the bulk of the accumulated mercury occurs naturally in crystalline lattices but anthropogenic activities cause the secondary accumulation of Mercury (Grimaldi, Guédron & Grimaldi, 2015). This occurs through the soil disturbance which tends to impede soil drainage and thereby favouring methylation of Hg (Grimaldi *et al.*, 2015; Guedron *et al.*, 2011b). Further, the studies on ASGM activities have reported the concentration levels of several known heavy metals which include As, Cd, Cr, Pb alongside other metals such as aluminium, copper, manganese, nickel, selenium, and zinc metals. These studies include those done in ASGM sites in Ghana (Basu *et al.*, 2015; Obiri *et al.*, 2016), Ecuador (Miserendino *et al.*, 2013). According to these studies, there is a link between ASGM activities and prevalence of these metals. There is no evidence to support their introduction of these selected metals into ASGM mining nor dispute the occurrence of the heavy metals in the mining processes. The only artificial ingredient introduced is the mercury which is used in the amalgamation process. Thus, processing of gold tends to release residual toxic materials into the environment while concentrating heavy metals (Razanamahandry *et al.*, 2018).

4. Conclusion

The study has shown that ASGM activity despite being an informal activity is growing in leaps and bounds and significantly contributes to economies of developing countries in Africa, Asia and South America. The use of Mercury among the miners is synonymous with the mining activity itself because of the lack of options. On one hand, the prices of gold in the international markets rump up the demand for gold and this, in turn, increases the prospectors who will use the easiest route to obtaining gold nuggets, that is the use of mercury. Thus, the process introduces and concentrates the heavy metals in the environments. Further, the study showed that most common metals in the ASGM sites are Mercury, Lead, Chromium, Cadmium and Arsenic which are derived anthropogenically into the environments by these activities. In time, their concentrations may breach the WHO/FAO concentration levels guidelines and pose a serious threat to the socio-ecological system. And because many ASGM communities in Sub-Saharan Africa are completely unaware of the dangers of the exposure of the heavy metals, they continue to mine without due care of the effects of the heavy metals.

5. Recommendation

ASGM has proved to be a significant livelihood and complementary activity to agriculture in sub-Saharan Africa and therefore this activity should be given due attention. ASGM is a resilient activity with a great propensity for grass-roots organization and management, and such capacity should be built upon and supported. The health and environmental standards should be encouraged and followed through. The policymakers should seek ways to improve practices in ASGM among them is the reduction or introduction of mercury-free technologies and general training and occupational health and safety measures. Importantly, improvements in the ASGM practices geared towards safeguarding the socio-ecological systems can be cost-effective and beneficial to the environmental and economic performance of an ASGM community, thereby initiating change in the sector.

6. Suggestion for Further Studies

The study was limited to the identification of selected heavy metals in artisanal mining activities in the North Rift region, Kenya and this leaves avenues for other studies relating to ASGM activities in the region. Therefore,

future studies may attempt to focus on the socio-economic impacts of ASGM activities, the health risks posed by ASGM activities and other related issues.

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